

AMENDMENT
(Amendment by Regulation of Law Article 11)

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1. Identification of the International Application

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4. Object of Amendment Specification and Claims

5. Content of Amendment

(1) In Specification, p.5, Lines 14 - 15, p.5, Lines 28 - 29, p.7, Line 1 and Line 26, and p.8, Line 19 (English Translation p.6, [0019] Lines 4 - 5) "and which when formed do not require lattice strain", and (English Translation p.8, [0026] Line 5, p.9, [0029] Line 5, and p.10, [0032] Line 5) "formed without requiring lattice strain" are deleted.

(2) In Specification, p.5, Lines 23 - 24 (English Translation p.6, [0021] Lines 3

- 4) "formed without requiring lattice strain" is deleted.

(3) In Specification, p.5, Lines 25 - 26 (English Translation p.6, [0021] Lines 4 - 8) "characterized in that the structure has at least one layer of such non-uniform quantum dots and; the quantum dots in the layer are non-uniform dots individually composed of compound semiconductor and different in one or both of size and compound semiconductor composition." is amended to:

"characterized in that the structure has at least one layer of such non-uniform quantum dots and; the non-uniform dots have a plurality of quantum levels as the light emission center corresponding to multi wavelengths including at least any of ultraviolet, visible light, and infrared light involving 1.3 and 1.5 μ m bands."

(4) In Specification, p.5, the bottom line (English Translation p.6, [0022] Lines 5 - 8) "includes at least one layer of non-uniform quantum dots formed - - - whereby the semiconductor multi-layered structure contains non-uniform quantum dots." is amended to:

"includes at least one layer, and each of non-uniform quantum dots are non-uniform dots individually composed of compound semiconductor and different in one or both of size and compound semiconductor composition, and said non-uniform quantum dots have a plurality of quantum levels as the light emission center by current injection corresponding to multi wavelengths including at least any of ultraviolet, visible light, and infrared light involving 1.3 and 1.5 μ m bands."

(5) In Specification, p.6, Lines 1 - 3 (English Translation p.6 to p.7, [0022] Line 8 to Line 11) "Then, the quantum dot layer included in the active layer is, preferably, formed of non-uniform quantum dots composed of compound semiconductor composition. Also," is deleted.

(6) In Specification, p.6, Line 5, p.7, Line 10, Lines 11 - 12, Line 18, p.8, Lines 6 - 7, and Line 28 (English Translation p.7, [0023] Line 1, p.8, [0027] Line 8, Line 9, [0028] Line 2, p.9, [0031] Line 2, and p.10, [0034] Line 2) "InAs or" is deleted.

(7) In Specification, p.6, Line 10 (English Translation p.7, [0023] Lines 2 - 7) "is made of one of materials selected from the class consisting of InP, $\text{Al}_x\text{In}_{1-x}\text{As}$ (where $x = 0.27$ to 0.65 and it has a forbidden band at room temperature of 0.95 eV to 1.9 eV), $\text{Ga}_x\text{In}_{1-x}\text{As}_y\text{P}_{1-y}$ (where $0 < x < 1$ and $0 < y < 1$), and $\text{Al}_u\text{Ga}_v\text{In}_w\text{As}$ (where $u + v + w = 1$, and it has a forbidden band at room temperature of 0.95 eV to 1.9 eV)" is amended to:

"is made of one of materials selected from the class consisting of InP, $\text{Al}_x\text{In}_{1-x}\text{As}$ (where $x = 0.27$ to 0.65 and it has a forbidden band at room temperature of 0.95 eV to 1.9 eV), $\text{Ga}_x\text{In}_{1-x}\text{As}_y\text{P}_{1-y}$ (where $0 < x < 1$ and $0 < y < 1$),

and $\text{Al}_u\text{Ga}_v\text{In}_w\text{As}$ (where $u + v + w = 1$, and it has a forbidden band at room temperature of 0.95 eV to 1.9 eV), and said non-uniform quantum dots have a plurality of quantum levels as the light emission center by current injection corresponding to multi wavelengths including at least either of infrared light involving 1.3 and 1.5 μm bands.”

(8) In Specification, p.6, Line 19 (English Translation p.7, [0023] Line 17) after “1.3 eV to 1.46 eV)” is added:

“And non-uniform quantum dots may have a plurality of quantum levels as the light emission center by current injection corresponding to multi wavelengths including at least either of infrared light involving 1.3 and 1.5 μm bands.”

(9) In Specification, p.6, Lines 26 - 27 (English Translation p.7, [0025] Lines 5 - 7) “and a layer of non-uniform quantum dots contained in at least one of the semiconductor layers and formed without requiring lattice strain,” is amended to:

“and a non-uniform quantum dot layer contained in a p-type or an n-type semiconductor layer”.

(10) In Specification, p.6, Line 27, p.7, Line 3, Line 28, and p.8, Line 21 (English Translation p.8, [0025] Line 10, [0026] Line 11, and p.9, [0029] Line 11) after “predetermined wavelengths.”, and p.10, [0032] Line 11 after “junction structure.” are added:

“Each of non-uniform quantum dots are non-uniform dots individually composed of compound semiconductor and different in one or both of size and compound semiconductor composition, and said non-uniform quantum dots have a plurality of quantum levels as the light emission center by current injection corresponding to multi wavelengths including at least any of ultraviolet, visible light, and infrared light involving 1.3 and 1.5 μm bands.”

(11) In Specification, p.7, Lines 6 - 10 (English Translation p.8, [0027] Lines 1 - 7) “the quantum dots are non-uniform quantum dots individually composed of compound semiconductor and different in one or both of size and compound semiconductor composition. Also, the said wavelengths - - -, visible light, and infrared light including a 1.3 μm band and a 1.5 μm band. Further,” is deleted.

(12) In Specification, p.8, Lines 2 - 6 (English Translation p.9, [0030] Lines 1 - 7) “In the semiconductor laser diode mentioned above, specifically the quantum dots in the layer are non-uniform quantum dots individually composed of compound semiconductor and different in one or both of size and compound semiconductor composition. Also, these wavelengths are specifically laser oscillation wavelengths including at least wavelengths of any of ultraviolet light, visible light, and infrared light including a 1.3 μm

band and a 1.5 μ m band.” is deleted.

(13) In Specification, p.8, Lines 24 - 28 (English Translation p.10, [0033] Lines 1 - 7) “In the semiconductor light amplifier mentioned above, the quantum dots in the layer are specifically non-uniform quantum dots individually composed of compound semiconductor and different in one or both of size and compound semiconductor composition. The said wavelengths may be amplification wavelengths including at least wavelengths of any of ultraviolet light, visible light, and infrared light including a 1.3 μ m band and a 1.5 μ m band.” is deleted.

(14) In Specification, p.9, Line 1 (English Translation p.10, [0034] Line 4) “x = 0.27” is amended to “x = 0.27”. (English Translation already has the amended version.)

(15) In Specification, p.9, Lines 12 - 15 (English Translation p.11, [0036] Lines 4 - 7) “characterized in that it includes the step of fabricating the non-uniform quantum dot structure for the semiconductor device by an epitaxial growth process that does not require lattice strain in forming non-uniform quantum dots.” is amended to:

“characterized in that it includes the step of fabricating the non-uniform quantum dot structure for the semiconductor device by an epitaxial growth process that does not require lattice strain in forming non-uniform quantum dots, and in this case the non-uniform quantum dot structure is formed by self-termination mechanism by the droplet epitaxial process using any of MOCVD, MBE, gas source MBE, and MOMBE processes.”

(16) In Specification, p.9, Lines 18 - 22 (English Translation p.11, [0037] Lines 1 - 7) “The said epitaxial growth process may be any one of MOCVD, MBE, gas source MBE, and MOMBE processes and a layer of the non-uniform quantum dots may be fabricated by a droplet epitaxial growth process which does not require lattice strain in forming non-uniform quantum dots. The non-uniform quantum dot layer may be formed by an auto-terminating mechanism in said droplet epitaxial growth process.” is deleted.

(17) In Specification, p.9, Line 22 (English Translation p.11, [0037] Line 7) “Specifically, the said epitaxial growth process is” is amended to:

“Specifically, a non-uniform quantum dot structure of a semiconductor device is formed with non-uniform dots individually composed of compound semiconductor and different in one or both of size and compound semiconductor composition. Also preferably, the quantum dot structure consists of either InAs or $\text{Ga}_x\text{In}_{1-x}\text{As}$ (where $0 < x \leq 0.6$). And more specifically, the said epitaxial growth process is”.

(18) In Specification, p.9, Line 28 (English Translation p.11, [0038] Line 7)

after "a large number of wavelengths." is added:

"Further, the present invention is characterized in that it is a semiconductor device manufactured by the above-mentioned method. In accordance with this aspect, a semiconductor device can be obtained which has a semiconductor multi-layered structure having a non-uniform quantum dot structure formed without requiring lattice strain by a droplet epitaxial growth process. Such a semiconductor device can be a light emission diode, a semiconductor laser diode, or a semiconductor light amplifier, capable of multi wavelength light emission and multi wavelength light amplification."

(19) In Claims, p.42, Claim 1, Lines 1 - 3 (English Translation Claims p.52, Claim 1, Line 2) "formed without requiring lattice strain" is deleted.

(20) In Claims, p.42, Claim 1, Lines 4 - 5 (English Translation Claims p.52, Claim 1, Lines 5 - 7) "the quantum dots in the layer are non-uniform quantum dots individually composed of compound semiconductor and different in one or both of size and compound semiconductor composition." is amended to:

"the quantum dots in the layer are non-uniform quantum dots individually composed of compound semiconductor and different in both of size and compound semiconductor composition, and said non-uniform quantum dots have a plurality of quantum levels as the light emission center by current injection corresponding to multi wavelengths including at least any of ultraviolet, visible light, and infrared light involving 1.3 and 1.5 μ m bands."

(21) In Claims, p.42, Claim 2, Line 3, Claims, p.44, Claim 9, Line 1, Claims, p.45, Claim 15, Line 1, and Claims, p.46, Claim 20, Line 1 (English Translation Claims p.52, Claim 2, Line 7, Claims p.54, Claim 9, Lines 4 - 5, Claims p.55, Claim 15, Line 5, and Claims p.57, Claim 20, Line 5) "formed without requiring lattice strain" is deleted.

(22) In Claims, p.42, Claim 2, Line 4 (English Translation Claims p.52, Claim 2, Line 6) "includes at least one layer" is amended to:

"includes at least one layer, and each of said non-uniform quantum dots is a non-uniform quantum dot individually composed of compound semiconductor and different in both of size and compound semiconductor composition, and said non-uniform quantum dots have a plurality of quantum levels as the light emission center by current injection corresponding to multi wavelengths including at least any of ultraviolet, visible light, and infrared light involving 1.3 and 1.5 μ m bands."

(23) In Claims, p.42, Claim 3, Claims, p.44, Claim 10 and Claim 11, Claims, p.45, Claim 16 and Claim 17, and Claims, p.47, Claim 21 and Claim 22 (English Translation Claims p.52, Claim 3, Claims p.54, Claim 10 and Claim 11, Claims p.56, Claim 16 and Claim 17, and Claims p.57, Claim 21 and Claim 22) are deleted.

(24) In Claims, p.42, Claim 4, Line 2 (English Translation Claims p.52, Claim 4, Line 2) "claim 2 or claim 3" is amended to:
"claim 2".

(25) In Claims, p.42, Claim 5, Line 1, Claims, p.43, Claim 6, Line 3, Claims, p.44, Claim 12, Lines 1 - 2, Claims, p.44, Claim 13, Line 1, Claims, p.45, Claim 14, Line 2, Claims, p.46, Claim 18, Line 2, and Claims, p.47, Claim 23, Line 2 (English Translation Claims p.52, Claim 5, Line 4, Claims p.53, Claim 6, Line 6, Claims p.54, Claim 12, Line 4, Claims p.55, Claim 13, Line 4, Claims p.55, Claim 14, Line 5, Claims p.56, Claim 18, Line 5, and Claims p.58, Claim 23, Line 5) "InAs or" is deleted.

(26) In Claims, p.43, Claim 5, Line 2, and Claims, p.43, Claim 6, Line 12 (English Translation Claims p.53, Claim 5, Line 11, and Claims p.53, Claim 6, Line 15) At the ends of Claim 5 and Claim 6 are added:

" , and said non-uniform quantum dots have a plurality of quantum levels as the light emission center by current injection corresponding to multi wavelengths including at least either of infrared lights involving 1.3 and 1.5 μ m bands."

(27) In Claims, p.43, Claim 5, Lines 2 - 3 (English Translation Claims p.52, Claim 5, Line 2) "any one of claims 2 to 4" is amended to:
"claim 2 or claim 4".

(28) In Claims, p.43, Claim 6, Lines 12 - 13 (English Translation Claims p.53, Claim 6, Line 2) "any one of claims 2 to 5" is amended to:
"claim 2 or claim 4".

(29) In Claims, p.43, Claim 7, Line 2 (English Translation Claims p.53, Claim 7, Line 2) "claims 2 to 6" is amended to:
"claim 2 and claims 4 - 6".

(30) In Claims, p.43, Claim 8, Lines 1 - 2 (English Translation Claims p.53, Claim 8, Lines 5 - 6) "contained in at least one of the semiconductor layers and formed without requiring lattice strain" is amended to:
"contained in either a p-type or an n-type semiconductor layer".

(31) In Claims, p.43, Claim 8, Line 3, Claims, p.44, Claim 9, Line 4, Claims, p.45, Claim 15, Line 4, and Claims, p.46, Claim 20, Line 4 (English Translation Claims p.53, Claim 8, Lines 3 - 6, Claims p.54, Claim 9, Lines 3 - 7, Claims p.55, Claim 15, Lines 4 - 9, and Claims p.57, Claim 20, Lines 4 - 9) after a clause of "it comprises (followed by such and such)", the line is changed, and is added:

"each of said quantum dots is a non-uniform quantum dot individually

composed of compound semiconductor and different in both of size and compound semiconductor composition, and said non-uniform quantum dots have a plurality of quantum levels as the light emission center by current injection corresponding to multi wavelengths including at least any of ultraviolet, visible light, and infrared light involving 1.3 and 1.5 μ m bands,”

(32) In Claims, p.44, Claim 12, Line 3 (English Translation Claims p.54, Claim 12, Lines 2 to 3) “any one of claims 8 to 10” is amended to:
“claim 8, or claim 9”.

(33) In Claims, p.45, Claim 13, Lines 1 - 2 (English Translation Claims p.55, Claim 13, Lines 2 - 3) “claims 9 to 12” is amended to:
“claims 9, 11 and 12”.

(34) In Claims, p.45, Claim 14, Line 8 (English Translation Claims p.55, Claim 14, Lines 2 - 3) “any one of claims 9 to 13” is amended to:
“claim 9”.

(35) In Claims, p.46, Claim 18, Lines 11 - 12 (English Translation Claims p.56, Claim 18, Line 3) “any one of claims 15 to 17” is amended to:
“claim 15”.

(36) In Claims, p.46, Claim 19, Line 2 (English Translation Claims p.57, Claim 19, Line 3) “any one of claims 15 to 18” is amended to:
“claim 15 or claim 18”.

(37) In Claims, p.47, Claim 23, Line 4 (English Translation Claims p.58, Claim 23, Line 7) “x = 027” is amended to:
“x = 0.27”. (English Translation already has the amended version.)

(38) In Claims, p.47, Claim 23, Lines 11 - 12 (English Translation Claims p.57, Claim 23, Line 3) “any one of claims 20 to 22” is amended to:
“claim 20”.

(39) In Claims, p.47, Claim 24, Line 2 (English Translation Claims p.58, Claim 24, Line 3) “any one of claims 20 to 23” is amended to:
“claim 20 or claim 23”.

(40) In Claims, p.48, Claim 25, Lines 3 - 5 (English Translation Claims p.58, Claim 25, Line 7) after “dots” is added:

“, and said non-uniform quantum dot structure of a semiconductor device is formed by epitaxial growth process without requiring lattice strain, and in this case, said non-uniform quantum dot structure is formed by auto-termination mechanism of a droplet epitaxial growth process using either of MOCVD, MBE, gas source MBE, or MOMBE method”

(41) In Claims, p.48, Claim 27, Lines 1 - 4 (English Translation Claims p.58 - 59, Claim 27, Lines 3 - 8) "said epitaxial growth process comprises any one of MOCVD, MBE, gas source MBE and MOMBE processes and a layer of the non-uniform quantum dots is fabricated by a droplet epitaxial growth process which does not require lattice strain in forming non-uniform quantum dots." is amended to:

"said non-uniform quantum dot structure of a semiconductor device is a non-uniform quantum dot individually composed of compound semiconductor and different in either one or both of size and compound semiconductor composition."

(42) In Claims, p.48, Claim 28, Lines 1 - 2 (English Translation Claims p.59, Claim 28, Lines 3 - 4) "the non-uniform quantum dot layer is formed by an auto-terminating mechanism" is amended to:

"said quantum dot structure consists of InAs, or $Ga_xIn_{1-x}As$ (where $0 < x \leq 0.6$)".

(43) In Claims, p.48, Claim 29, Lines 3 - 4 (English Translation Claims p.59, Claim 29, Line 3) "any one of claims 25 to 28" is amended to:

"claim 25".

(44) In Claims, p.48, Claim 29, (English Translation Claims p.59, Claim 29) after Claim 29 is added Claim 30 as:

"30. A semiconductor device, characterized in that it is manufactured by the method of manufacture of semiconductor devices using a semiconductor multi-layered structure having non-uniform quantum dots as set forth in any one of claims 25 - 29."

6. List of Attached Documents

(1) Specification p.5, 5/1, 6, 6/1, 7, 7/1, 8, 9, 9/1

(English Translation p.6, 6/1, 7, 7/1, 8, 8/1, 9, 9/1, 10, 10/1, 11, 11/1)

(2) Claims p.42, 43, 43/1, 44, 45, 46, 47, 48, 48/1

(English Translation p.52, 52/1, 53, 53/1, 54, 55, 55/1, 56, 57, 58, 58/1, 59)

LED having a practical luminous intensity has not been obtained.

Disclosure of the Invention

[0019] In view of the problems mentioned above it is an object of the present invention to provide a semiconductor multi-layered structure having non-uniform quantum dots which are capable of light emission or amplification in a broad wavelength range, and also to provide a light emitting diode, a semiconductor laser diode and a semiconductor light amplifier using the same as well as a method of making them.

[0020] The present inventors upon having uniquely devised a method of making a non-uniform quantum dot structure that can be formed by droplet hetero-epitaxy without requiring lattice strain, have pioneered in the world in succeeding to observe light emission in a band around $1.3\ \mu\text{m}$ to a band around $1.5\ \mu\text{m}$ from quantum dots by current injection and have reached accomplishing the present invention.

[0021] In order to achieve the object mentioned above, there is provided in accordance with the present invention a semiconductor multi-layered structure having quantum dots characterized in that the structure has at least one layer of such non-uniform quantum dots and; the non-uniform quantum dots have a plurality of quantum levels as the light emission center corresponding to multi wavelengths including at least any of ultraviolet, visible light, and infrared light involving 1.3 and $1.5\ \mu\text{m}$ bands.

[0022] The present invention also provides a semiconductor multi-layered structure that is of a double hetero junction structure comprising an active layer, and a pair of clad layers laid on opposite sides of the active layer and larger in forbidden band than the active layer, characterized in that the active layer includes at least one layer, and each of non-uniform quantum dots are non-uniform dots individually composed of compound semiconductor and different in one or both of size and compound semiconductor composition, and said non-uniform quantum dots have a plurality of quantum levels as the light emission center by current injection corresponding to multi

wavelengths including at least any of ultraviolet, visible light, and infrared light involving 1.3 and 1.5 μ m bands.

The structure may then be taken that a plurality of such non-uniform quantum dot layers are embedded in the active layer.

[0023] Preferably, the quantum dots are made of $\text{Ga}_x\text{In}_{1-x}\text{As}$ (where $0 < x \leq 0.6$); and the active layer is made of one of materials selected from the class consisting of InP , $\text{Al}_x\text{In}_{1-x}\text{As}$ (where $x = 0.27$ to 0.65 and it has a forbidden band at room temperature of 0.95 eV to 1.9 eV), $\text{Ga}_x\text{In}_{1-x}\text{As}_y\text{P}_{1-y}$ (where $0 < x < 1$ and $0 < y < 1$), and $\text{Al}_u\text{Ga}_v\text{In}_w\text{As}$ (where $u + v + w = 1$, and it has a forbidden band at room temperature of 0.95 eV to 1.9 eV), and said non-uniform quantum dots have a plurality of quantum levels as the light emission center by current injection corresponding to multi wavelengths including at least either of infrared light involving 1.3 and $1.5 \mu\text{m}$ bands. Alternatively, the semiconductor multi-layered structure having the non-uniform quantum dots has a substrate made of InP ; the quantum dots are made of InAs or $\text{Ga}_x\text{In}_{1-x}\text{As}$ (where $0 < x \leq 0.6$); the active layer is made of $\text{Al}_x\text{In}_{1-x}\text{As}$ (where $x = 0.27$ to 0.40 and it has a forbidden band at room temperature of 0.95 eV to 1.24 eV) or $\text{Al}_u\text{Ga}_v\text{In}_w\text{As}$ (where $u + v + w = 1$, and it has a forbidden band at room temperature of 0.95 eV to 1.24 eV); and the clad layers are made of $\text{Al}_x\text{In}_{1-x}\text{As}$ (where $x = 0.42$ to 0.48 and it has a forbidden band at room temperature of 1.3 eV to 1.46 eV) or $\text{Al}_x\text{Ga}_y\text{In}_z\text{As}$ (where $x + y + z = 1$, and it has a forbidden band at room temperature of 1.3 eV to 1.46 eV). And non-uniform quantum dots may have a plurality of quantum levels as the light emission center by current injection corresponding to multi wavelengths including at least either of infrared light involving 1.3 and $1.5 \mu\text{m}$ bands. It is desirable that the active layer be lattice-matching with the clad layers.

[0024] According to these features of the invention, there are advantageously produced a large number of quantum levels resulting from the non-uniform quantum dot structure formed inside of the semiconductor or semiconductor hetero junction. There is thus provided a semiconductor multi-layered structure having non-uniform quantum dots capable of light emission or amplification in multi wavelengths originating from these quantum levels.

[0025] The present invention further provides a light emitting diode

using a semiconductor multi-layered structure having non-uniform quantum dots, characterized in that it comprises a p-type semiconductor layer and an n-type semiconductor layer which together form a pn diode; and a non-uniform quantum dot layer contained in a p-type or an n-type semiconductor layer, whereby injecting current into the

said pn diode causes the non-uniform quantum dots to be excited, thereby emitting light therefrom in a multi of predetermined wavelengths. Each of non-uniform quantum dots are non-uniform dots individually composed of compound semiconductor and different in one or both of size and compound semiconductor composition, and said non-uniform quantum dots have a plurality of quantum levels as the light emission center by current injection corresponding to multi wavelengths including at least any of ultraviolet, visible light, and infrared light involving 1.3 and 1.5 μ m bands.

[0026] The present invention also provides a light emitting diode using a semiconductor multi-layered structure having non-uniform quantum dots, characterized in that it comprises an active layer containing a semiconductor multi-layered structure having non-uniform quantum dots; and a double hetero junction structure comprising the active layer and clad layers formed at opposite sides of the active layer and larger in forbidden band than the active layer, whereby injecting current into the double hetero junction structure causes the non-uniform quantum dots to be excited, thereby emitting light in multi predetermined wavelengths. Each of non-uniform quantum dots are non-uniform dots individually composed of compound semiconductor and different in one or both of size and compound semiconductor composition, and said non-uniform quantum dots have a plurality of quantum levels as the light emission center by current injection corresponding to multi wavelengths including at least any of ultraviolet, visible light, and infrared light involving 1.3 and 1.5 μ m bands.

[0027] In the light emitting diode mentioned above, the light emitting diode may have a substrate made of InP; and the quantum dots may be made of $\text{Ga}_x\text{In}_{1-x}\text{As}$ (where $0 < x \leq 0.6$). When the dots are made of $\text{Ga}_x\text{In}_{1-x}\text{As}$ (where $0 < x \leq 0.6$), the active layer may also be made of one of materials selected from the class consisting of InP, $\text{Al}_x\text{In}_{1-x}\text{As}$ (where $x = 0.27$ to 0.65 and it has a forbidden band at room temperature of 0.95 eV to 1.9 eV), $\text{Ga}_x\text{In}_{1-x}\text{As}_y\text{P}_{1-y}$ (where $0 < x < 1$ and $0 < y < 1$), and $\text{Al}_u\text{Ga}_v\text{In}_w\text{As}$ (where $u + v + w = 1$, and it has a forbidden band at room temperature of 0.95 eV to 1.9 eV).

[0028] When, the light emitting diode has a substrate made of InP; the quantum dots are made of $\text{Ga}_x\text{In}_{1-x}\text{As}$ (where $0 < x \leq 0.6$); the active layer is made of $\text{Al}_x\text{In}_{1-x}\text{As}$ (where $x = 0.27$ to 0.40 and it has a forbidden band at room temperature of 0.95 eV to 1.24 eV) or $\text{Al}_u\text{Ga}_v\text{In}_w\text{As}$ (where $u + v + w = 1$, and it has a forbidden band at room temperature of 0.95 eV to 1.24 eV), then the clad layers may be

made of InP. According to these features, strong light emission can be obtained in multi wavelengths arising from transitions via the quantum levels of non-uniform quantum dots.

[0029] The present invention also provides a semiconductor laser diode using a semiconductor multi-layered structure having non-uniform quantum dots, characterized in that it comprises an active layer containing at least one layer of non-uniform quantum dots; and a double hetero junction structure comprising the active layer and clad layers formed at opposite sides of the active layer and larger in forbidden band than the active layer, whereby injecting current into the double hetero junction structure causes the non-uniform quantum dots to be excited, thereby bringing about laser oscillations in multi predetermined wavelengths. Each of non-uniform quantum dots are non-uniform dots individually composed of compound semiconductor and different in one or both of size and compound semiconductor composition, and said non-uniform quantum dots have a plurality of quantum levels as the light emission center by current injection corresponding to multi wavelengths including at least any of ultraviolet, visible light, and infrared light involving 1.3 and 1.5 μ m bands.

[0030]

[0031] The semiconductor laser diode has a substrate specifically made of InP; and then the quantum dots may be made of $\text{Ga}_x\text{In}_{1-x}\text{As}$ (where $0 < x \leq 0.6$); the active layer may be made of $\text{Al}_x\text{In}_{1-x}\text{As}$ (where $x = 0.27$ to 0.40 and it has a forbidden band at room temperature of 0.95 eV to 1.24 eV) or $\text{Al}_u\text{Ga}_v\text{In}_w\text{As}$ (where $u + v + w = 1$, and it has a forbidden band at room temperature of 0.95 eV to 1.24 eV); and the clad layers may be made of $\text{Al}_x\text{In}_{1-x}\text{As}$ (where $x = 0.42$ to 0.48 and it has a forbidden band at room temperature of 1.3 eV to 1.46 eV) or $\text{Al}_x\text{Ga}_y\text{In}_z\text{As}$ (where $x + y + z = 1$, and it has a forbidden band at room temperature of 1.3 eV to 1.46 eV). Preferably, the active layer is lattice-matching with the clad layers. According to these features of the invention, laser light can be obtained in multi wavelengths arising from transitions via a plurality of quantum levels of a layer of non-uniform quantum dots included in the active

layer.

[0032] The present invention also provides a semiconductor light amplifier using a semiconductor multi-layered structure having non-uniform quantum dots, characterized in that it comprises an active layer containing at least one layer of non-uniform quantum dots; and a double hetero junction structure comprising the active layer and clad layers formed at opposite sides of the active layer and larger in forbidden band than the active layer, whereby injecting current into the double hetero junction structure causes the non-uniform quantum dots to be excited, thereby amplifying light in multi predetermined wavelengths incident externally of the double hetero junction structure. Each of non-uniform quantum dots are non-uniform dots individually composed of compound semiconductor and different in one or both of size and compound semiconductor composition, and said non-uniform quantum dots have a plurality of quantum levels as the light emission center by current injection corresponding to multi wavelengths including at least any of ultraviolet, visible light, and infrared light involving 1.3 and 1.5 μm bands.

[0033]

[0034] Also, the semiconductor light amplifier may have a substrate made of InP; the quantum dots may be made of $\text{Ga}_x\text{In}_{1-x}\text{As}$ (where $0 < x \leq 0.6$); the active layer may be made of $\text{Al}_x\text{In}_{1-x}\text{As}$ (where $x = 0.27$ to 0.40 and it has a forbidden band at room temperature of 0.95 eV to 1.24 eV) or $\text{Al}_u\text{Ga}_v\text{In}_w\text{As}$ (where $u + v + w = 1$, and it has a forbidden band at room temperature of 0.95 eV to 1.24 eV); and the clad layers may be made of $\text{Al}_x\text{In}_{1-x}\text{As}$ (where $x = 0.42$ to 0.48 and it has a forbidden band at room temperature of 1.3 eV to 1.46 eV) or $\text{Al}_x\text{Ga}_y\text{In}_z\text{As}$ (where $x + y + z = 1$, and it has a forbidden band at room temperature of 1.3 eV to 1.46 eV). Preferably, the active layer is lattice-matching with the clad layers.

[0035] According to these features, light amplification can be attained in multi wavelengths arising from transitions via a plurality of quantum levels of a layer of non-uniform quantum dots included in the active layer.

[0036] The present invention further provides a method of making a

semiconductor device using a semiconductor multi-layered structure

having non-uniform quantum dots in a non-uniform quantum dot structure, characterized in that it includes the step of fabricating the non-uniform quantum dot structure for the semiconductor device by an epitaxial growth process that does not require lattice strain in forming non-uniform quantum dots, and in this case the non-uniform quantum dot structure is formed by self-termination mechanism by the droplet epitaxial process using any of MOCVD, MBE, gas source MBE, and MOMBE processes. The said semiconductor device may be any one of a light emitting diode, a semiconductor laser diode and a semiconductor light amplifier.

[0037] Specifically, a non-uniform quantum dot structure of a semiconductor device is formed with non-uniform dots individually composed of compound semiconductor and different in one or both of size and compound semiconductor composition. Also preferably, the quantum dot structure consists of either InAs or $Ga_xIn_{1-x}As$ (where $0 < x \leq 0.6$). And more specifically, the said epitaxial growth process is MOCVD and the non-uniform quantum dot layer is formed by droplet epitaxial growth at a growth temperature lower than that at which other growth layers in the structure are formed.

[0038] According to the methods mentioned above, using the droplet epitaxial growth process can form a semiconductor multi-layered structure including a structure of non-uniform quantum dots which when formed do not require lattice strain, thus enabling a light emitting diode, a semiconductor laser diode and a semiconductor light amplifier to be made which can emit or amplify light in a large number of wavelengths. Further, the present invention is characterized in that it is a semiconductor device manufactured by the above-mentioned method. In accordance with this aspect, a semiconductor device can be obtained which has a semiconductor multi-layered structure having a non-uniform quantum dot structure formed without requiring lattice strain by a droplet epitaxial growth process. Such a semiconductor device can be a light emission diode, a semiconductor laser diode, or a semiconductor light amplifier, capable of multi wavelength light emission and multi wavelength light amplification.

Brief Description of the Drawings

[0039] The present invention will better be understood from the following detailed description and the drawings attached hereto showing certain illustrative forms of implementation of the present invention. In this connection, it should be noted that such forms of implementation illustrated in the accompanying drawings hereof are intended in no way to limit the present invention but to facilitate an explanation and understanding thereof. In the drawings,

Fig. 1 is a typical view illustrating a cross section of a semiconductor multi-layered structure having non-uniform quantum